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ELSŐBBSÉGI TANÚSÍTVÁNY

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A Magyar Szabadalmi Hivatal tanúsítja, hogy

Optilink AB., Rönneby (SE),

Magyarországon

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Eljárás és rendszer információ rögzítésére holografikus kártyán

című találmányt jelentett be szabadalmazásra.
Az idefűzött másolat a bejelentéssel egyidejűleg benyújtott melléklettel mindenben megegyezik.

Budapest, 1999. év 05. hó 14. napján

a Szabadalmi Főosztály vezetője

The Hungarian Patent Office certifies in this priority certificate that the said applicant(s) filed a patent application at the specified date under the indicated title, application number and registration number. The attached photocopy is a true copy of specification filed with the application.

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ELSŐBBSÉGI PÉLDÁNY

1998 MÁJ 05.

Eljárás és rendszer információ rögzítésére holografikus kártyán

System and method for recording of information on a holographic recording medium, preferably an optical card

The present invention concerns a method and apparatus for the recording and reading of data on a recording medium, preferably an optical card, by holography. The invention also relates to an apparatus for use with the method of the invention. The apparatus uses a holographic recording medium, preferably an optical card, and holographic write/read optical system. The recording medium, preferably an optical card has a thin holographic recording layer, wherein the recording of the information is in the form of data pages stored as thin Fourier holograms. The invention further relates to a method for coding of the recorded information on a holographic optical recording medium, preferably an optical card. In the method, the information is recorded in the form of several discrete holograms recorded in different physical and/or logical recording locations on the optical recording medium, preferably an optical card. Each hologram containing data sets and the sequence of the data sets together constitute the recorded information.

BACKGROUND OF THE INVENTION

The known optical memory cards provide approx. 4-6 MB of data on a credit card sized optical card, and the reader/writer units offer 30-10 KB/s data transfer rate. Writing speeds are normally slower than reading speeds.

Holographic recording is known for its inherent high data density, and therefore has been suggested for use in a data storage card. A number of solutions have been proposed for incorporating holograms into data storage cards, but the hologram is mostly used for authentication purposes, and not for data storage. Using holograms to store data on a credit-card sized data card involves several problems.
First, most holographic techniques require that the photosensitive medium storing the hologram be illuminated from both sides, either during recording or during readout.

Accordingly, the recording medium, preferably an optical card holding the holograms should have an optical-quality surface on both sides, and have constant thickness. These requirements are difficult to meet with a conventional plastic card. Second, for data storage application it is desirable to use a recording medium that may be erased and re-recorded. There are very few erasable optical materials that are suitable for holographic recording, the achievable signal-to-noise ratio is relatively low and high exposition energy is needed. Third, with every readout, the recorded holograms will be slightly erased. To ensure the stability of the recorded holograms, different reading and writing wavelength is required, but in this case the reconstructed image of the hologram is distorted so much, that high-density storage is not possible.

A known method of reflection holography is disclosed in the publication DE 195 34 501 A1., and in the publication „High density disc storage by multiplexed microholograms", SPIE Vol. 3109, pp. 239-244. In these solutions a method is suggested to create reflection holograms. It is suggested to apply a mirror under the recording layer during the recording phase, so that the object beam reflected from the mirror will act as reference beam. Thereby no separate optical path is needed for the reference beam. It is suggested to multiply the storage capacity by different forms of multiplexing. The holograms are reconstructed as volume reflection holograms. A disadvantage of the proposed solution is that the mirror must be removed during readout, which makes this system unfit for practical optical recording systems. Also, there is no suggestion to use this method with an optical card.

Another form for reflection holography is disclosed in the US patent No. 5,633,100, which patent teaches a process for forming a volume reflection hologram. This known solution also require the use of a reference beam that is incident on the opposite surface of the photosensitive medium, so the solution is not practical for an optical card. US patent No. 4,888,260 discloses another method for the preparation of a volume phase reflection hologram. Here, the volume phase reflection hologram is formed by a second off-axis hologram in the same recording medium. This method is

not suitable for forming erasable and re-recordable holograms, and the optical system is very complicated. US patent No. 5,710,645 discloses a method and system for recording a grazing incidence hologram, which is supported on a substrate having a thin edge-illuminatable geometry, like an optical card. Theoretically, this system could be used for data storage as well, but again the edge-illumination demands very special mechanical and optical properties of the card carrying the hologram.

Therefore, it is the object of the invention to provide a method and system for data storage based on reflection holography, where the holograms may be recorded and erased several times, preferably in an unlimited number of cycles, and where the holograms need to be accessed from one side only, both during writing and readout. Also, the holograms should be stored on an optical recording medium, preferably an optical card or disk that is easy to manufacture, and which tolerates normal daily wear, i. e. which is subjected to the same or similar treatment as a traditional plastic credit card or a floppy disk. It is a further object of the invention to provide a method and system for data storage where the read-write apparatus contains a relatively small, simple and cheap optical system. It is a further object to provide an optical recording method that ensures high data density and high data transfer rate, and at the same time allow efficient encoding or encryption of the data, and thereby provides enhanced security.

According to the invention, this goal is achieved by a method, which uses a holographic write/read apparatus, and a recording medium, preferably an optical card, with a thin holographic recording layer. The holographic recording medium may be in the form of an optical disk or tape as well. The term „thin" means that the layer thickness is in the order of the light wavelength, and the holograms recorded may not be regarded as traditional volume holograms, so that the recording of the information is in the form of data pages stored as thin Fourier holograms.
According to the invention, reflected transmission and polarisation holography with different write and read wavelengths are used and further, the distortion is corrected

during reading, which distortion is caused by the difference between the write and read wavelengths.

The use of reflected transmission holography is a key element in the recording method of the invention. It has been proposed to overcome the problems involved with the illumination of or accessing of the hologram from two sides, either during recording or readout. Therefore, it is suggested to use a form of reflection holography, which will be referred to hereinafter as reflected transmission holography. In accordance with the invention, in this holographic recording method the recording layer is relatively thin, and there is a reflective layer under the recording layer. The readout of the hologram is performed in the transmission mode, but the transmitted object wave is reflected from the reflective layer, propagates through the recording medium, and is detected on the same side from which the reference wave arrives.

According to the invention, for the method it is suggested to use a holographic recording medium, such as a memory card having a carrier substrate, a holographic recording layer sensitive to light, and a reflection layer between the carrier substrate and the recording layer. In the recording medium of the invention, preferably an optical memory card, the recording layer is a polarisation sensitive polymer material, and the thickness of the recording layer is 0.5-2 times the wavelength of the reading and/or recording light.

The method is realised with an apparatus for the writing and reading of a holographic recording medium, preferably an optical card, having a recording medium holding and/or positioning mechanism, movable or fixed read and write optics, where the write optics comprising a polarised writing light source, a polarising beam selector for separating the reference beam and the object beam, an object beam modulating unit, a polarisation wave plate, an objective lens for imaging the object beam onto a recording layer, and further the read optics comprising a polarised reading light source, and a polarisation selective beam splitter for separating the reference beam and the image

beam, a light detector and an objective lens for imaging the image beam onto a light detector. In the apparatus according to the invention, the wavelength of the reading light source is different from the writing light source, and the read optics comprise wavelength distortion correcting means for correcting the distortion of the reconstructed image caused by the difference in the wavelength of the reading and writing light.

The invention also includes a holographic data storage system with a holographic recording medium, and a read/write apparatus for the holographic recording medium, preferably an optical card, particularly with the recording medium and the read/write apparatus according to the invention. The proposed system utilises reflected transmission and polarisation holograms with different read and write wavelengths, together with distortion correction means for correcting the distortion caused by the difference between the read and write wavelengths.

According to the invention, there is also provided a method wherein the wavelength distortion is corrected by optical and/or software means. In the most preferred embodiment the correction is performed by an appropriately designed lens system and the holograms are recorded as on-axis holograms, using the advantages of the polarisation recording.

It is suggested that the recording and reading is made with polarisation multiplexing and/or phase-code multiplexing. Especially the so-called deterministic phase-code multiplexing is foreseen, which may increase capacity by an order of magnitude, and also contributes to the encryption of the data, as will be shown below.

In a special embodiment of the holographic recording medium of the invention, preferably an optical card, the reflection layer is a wavelength selective mirror reflecting on the read wavelength and transmitting or absorbing on the write wavelength. This arrangement greatly improves the sensitivity of the recording.

In a further embodiment, the holographic medium is a write-once or erasable-rewritable holographic medium, preferably a side-chain polyester (SCP), most preferably azobenzene SCP. Azobenzene SCP is a novel holographic material, allowing the recording of high-density data storage using polarisation holography.

Advantageously, the wavelength of the writing light source of the apparatus of the invention is between 400-500 nm, and the wavelength of the reading light source is between 600-700 nm. Such light sources are readily available in the forms of laser diodes, allowing the construction of small and robust optical read/write systems.

In the most preferred embodiment, the wavelength distortion correcting means of the read optics comprises an aspherical plastic objective lens.

It is contemplated that the object beam and the reference beam in the read optics and/or the write optics have a common optical axis, and there is provided a polarisation selective beam splitter for separating the reflected reference beam from the reflected object beam. This is feasible, because the polarisation holography technique suggested allows the separation of the reference beam from the object beam, and the SNR of the readout is high.

Advantageously, polarisation encoder means, especially liquid crystal spatial light modulators (LCSLMs) are provided in the optical path of the reference beam. These devices allow the use of phase code multiplexing.

It has been found practical and feasible for the read optics and the write optics to have a common objective lens for imaging the reference and object beams onto a recording layer and for imaging the reflected object beams onto the read detector. Thereby the optical system may be compact and lightweight, and the positioning system is simpler. Also, direct readout after recording is possible, practically without any delay.

In an especially preferred embodiment of the apparatus, the common objective lens is an aspheric lens for the correction of the wavelength distortion, where a central region of the aspheric lens is tuned to the wavelength of the writing light source for focussing the write object beam onto the recording layer and at the same time tuned to the wavelength of the read light source for imaging the read object beam onto the detector, and further the annular region of the lens is tuned to the wavelength of the read light source for imaging the reflected beam onto the detector.

In a further preferred embodiment of the optical system of the invention, the holographic record and readout optics comprise means for reading and/or writing multiplexed holograms. For example, using deterministic phase encoding multiplexing, the information density of a hologram may be increased in theory by several magnitudes. In a practically viable system, multiplexing with a factor of ten to hundred is possible.

Using the advantageous properties of the holographic recording method and the recording medium of the invention, preferably an optical card, it is also proposed to implement a novel method for the coding of the recorded information on the holographic optical recording medium, preferably an optical card. The method comprises the recording of the information in the form of several discrete holograms and/or subholograms recorded in different physical and/or logical recording locations on the optical recording medium, preferably an optical card. These holograms or subholograms contain data sets, where the sequence of the data sets together constitute the recorded information. According to the inventive method, the data sets are recorded in a random sequence of the recording locations. If the sequence of the recording is not readily known, the access to the data is effectively blocked. The method requires relatively little excess memory capacity, but at the same time it is very effective.
It is also contemplated that the information is recorded in multiplexed holograms, and the logical recording locations are identified by the multiplexing address. In the most

preferred embodiment, the information is recorded by polarisation holography using phase-code multiplexing, where one hologram contains several phase-coded multiplexed subholograms. The logical recording locations are identified by the phase code address.

In a further improved implementation, the location of the first data set is stored, and the location of the following data sets are stored in the previous data sets. It is especially foreseen that the physical recordings follow each other in an ordered sequence, but that the phase code addresses change randomly. Thereby the readout data rate can be maintained at a high level, but the encoding is still ensured. In an optional preferred realisation of the method, the random sequence of the data sets is stored and encrypted and/or made inaccessible for unauthorised users. This latter solution may facilitate the faster readout of the data.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will now be described in more detail herein below with reference to the accompanying drawings, which, by way of example only, illustrate preferred embodiments of the methods, apparatus and the system according to the invention, together with the optical recording recording medium, preferably an optical card.

In the drawings

Fig. 1. shows a schematic diagram of the functional blocks of the optical storage system,

Fig. 2a-b shows a schematic diagram of the holographic read/write optics of the system and apparatus according to a preferred embodiment of the invention,

Fig. 3 shows a schematic diagram of the holographic read/write optics of the system and apparatus according to another preferred embodiment of the invention,

Fig. 4a-b shows a schematic cross-section of the optical recording medium, preferably an optical card, utilised in the optical system of the invention, and illustrates the principle of the holographic recording method in accordance of the invention,

Fig. 5 shows the layout of the data on the optical card of the invention, and illustrates the method used for encoding of the information,

Fig. 6a-b shows the side and top view of the means for the correction of the wavelength distortion in the read/write optics of Fig. 3,

Fig 7 shows a schematic diagram of the mechanical positioning system of the apparatus according to the invention.

Detailed description

Fig. 1 shows the block diagram of the optical storage system 1 of the invention. The holographic optical storage system 1 comprises the optical recording medium, preferably an optical card 2, which is normally fixed on the card positioning unit 4. It must be emphasised that instead of the optical card, an optical disk or tape is also suitable to realise the invention. The optical card 2 is read and written (recorded) by the card read/write optics 3. The functions of the optical storage system 1 are controlled by the main controller 5, which is practically a microprocessor. The main controller 5 is controlling the data processor 6 and the synchronising circuit 8, and further the positioning controller 9. The main controller 5 is also connected to the interface 7. Data input and output are effected through the interface 7, and the data are processed by the data processor 6. Synchronising circuit 8 synchronises the read/write functions of the read/write optics 3 with the positioning functions of the positioning controller 9.

Fig. 2 illustrates the optical system of the holographic read/write optics 3 of Fig. 1. In the embodiment of Fig. 2, the holographic read/ write optics 3 has a write optics part 51 and a read optics part 52. These two parts may be fully separated, having a separate

moving system, but in a practical embodiment the two parts are moved together with a common positioning system. In another preferred embodiment, the write optics part 51 and a read optics part 52 are fixed, and the optical card 2 is positioned relative to the optics by the positioning mechanism 4 of Fig. 1 (see also Fig. 7.).

The write optics part 51 comprises the write laser 20, operating in the visible blue region, around 440 nm. The write laser 20 is preferably a semiconductor laser, but other types of laser are also suitable. However, the laser used for the recording must have a sufficient coherence length, i. e. longer than the path difference between the object beam and the reference beam. The beam of the write laser 20 is directed through the half-wave-plate 24, the beam shaping optics 22 and the beamsplitter 23. The beam-shaping optics 22 transforms the Gaussian intensity distribution of the laser 20 into a square distribution in a known manner. The purpose of this transformation is to provide uniform illumination in the whole object space, i. e. on the Object SLM (Spatial Light Modulator) 25. The polarising beamsplitter 23 separates the beam into the object beam 15 and the reference beam 16. After the polarising beamsplitter 23 the object beam 15 is parallel polarised, and the reference beam 16 is transversely polarised. The reference beam 16 is sent through the quarter-wave-plate 30, towards the reference SLM 26. The reference beam 16 is reflected from the reference SLM 26 back through the quarter wave-plate 30, the beamsplitter 23, another quarter wave-plate 35 and then falls on the surface of the optical card 2 through the objective lens 27, which will be described below.

After the beamsplitter 23 the object beam 15 falls on the object SLM 25 through the quarter-wave-plate 36. From the object SLM 25 the object beam 15 is deflected back towards the optical card 2, through the quarter-wave-plate 36, the beamsplitter 23, and the quarter wave-plate 35. The object beam 15 falls on the surface of the optical card 2 through the same objective lens system 27, with other words, the reference beam 16 and the object beam 15 has a common optical axis to and from the optical card 2. This configuration of the optical system is denoted as an on-axis configuration. The object

beam 15 and the reference beam 16 are modulated by their respective spatial light modulators 26 and 25, as will be described below. The SLMs 26 and 25 are preferably LCD devices, with 1024x1024 or 512x512 pixel segments, where the light reflecting properties of the individual segments may be controlled individually by a suitable circuit, in the invention the data processing circuit 6. The object SLM 26 is encoded with the data, while the reference SLM 25 is encoded with the phase address. With this embodiment, the object SLM 26 is a device that modulates the amplitude (intensity) of the transmitted light, but other types of SLM devices are also contemplated for use in the apparatus of the invention. E.g. matrix polarisation modulators are also applicable, where the polarisation angle may be controlled. As will be discussed below, the reference SLM 26 is a polarising SLM, which is capable of adding a π phase delay to the reference beam 16. The object beam 15 and the reference beam 16 are imaged on the optical card 2 by a suitable objective lens system, preferably by Fourier transform lenses, here symbolised with the lens system 27. It is understood that other, presently not discussed optical components, like lenses, diaphragms, mirrors, etc. may also be used, in order to get a suitable beam shape at the SLM 26 and 25 and on the surface of the optical card 2. Particularly, a known focus and tracking servo optics and mechanism is also foreseen to focus the object beam 15 and the reference beam 16 on well defined locations of the surface of the optical card 2.

With the embodiment of the read/write optics 3 shown in Fig. 2, the detection of the holograms on the optical card 2 is done with the read optics part 52. The read optics part 52 is similarly configured to the write optics 51, but the read laser 21 is a red laser. The read laser in this embodiment operates in the visible red region, between 600-700 nm, and is preferably another semiconductor laser or LED, or a He-Ne laser. Accordingly, the wave plates 30’ and 35’ are tuned for the wavelength of the read laser. Instead of the object SLM 25 and the wave-plate 36, there is a CCD detector 29. The hologram is imaged on the CCD detector 29 with suitable imaging optics, preferably Fourier transform lenses, here illustrated with the objective lens 28.

The CCD detector 29 reads out the data stored in the hologram, which contains the bitmap image of the object SLM 25.

The recorded information is in the form of data pages stored as thin Fourier holograms. This means that the holograms may not be treated as traditional volume holograms, but that they are thick enough, so that their thickness is not negligible. These holograms in accordance with the invention represent an intermediate case, where the diffraction pattern is between the so-called Bragg diffraction valid for thick gratings, and the Raman-Nath diffraction valid for infinitely thin gratings. The layer thickness used in the invention is practically between 300 nm and 3000 nm, which means that the resulting diffraction pattern is that of a finite layer thickness, with an appreciable wavelength and angle selectivity, but that these do not reach the selectivity of thick holograms.

According to the invention, the holographic recording is made by reflected transmission holography. The principle of this holographic recording method is explained with reference to Figs. 4a-b. Fig. 4a-b shows the cross-section of the optical card 2 and the reflective layer 32 underneath the recording layer 33. The recording layer 33 is relatively thin, and the reflective layer 32 is a wavelength selective layer, which reflects light on the readout wavelength, but absorbs (or alternatively transmits) light on the write wavelength. During recording (see Fig. 4a), the hologram 61 is created in the recording layer 33 of the card 2 by the polarisation interference pattern between the reference beam 16 and the object beam 15. In Fig. 4a-b the incident and reflected beams are shown at an angle to each other for the better illustration of the recording and reading process, but it must be stressed that in reality the beams are parallel, and have a common optical axis, at least in the preferred embodiments shown in the description.

During readout (see Fig. 4b), the incident reference beam 18 generates an object beam, which reproduces the information content of the original write object beam 15. The reproduced object beam would normally exit from the hologram 61 as transmitted object beam 19. But this transmitted object beam 19 is reflected on the reflective layer

32, propagates through the recording layer 33 one more time, and exits from the recording layer 33 as the reflected object beam 17. Of course, the reference beam 18 is also reflected as reflected reference beam 18', but this latter may be separated from the reflected object beam 17, using the polarisation properties of the beams, as will be shown below.

As explained above, in the reflected transmission holography process in accordance with the invention, the readout of the hologram is performed in the transmission mode, but the transmitted object wave is reflected from the reflective layer, propagates through the recording medium, and is detected on the same side from which the reference wave arrives.

The holographic recording process utilised in the invention is the so-called polarisation holography. Polarisation holographic recording is accomplished by two plane waves having mutually orthogonal polarisation. In this type of recording the resulting light field is not modulated by intensity but only by polarisation. The induced optical anisotropy (dichroism or birefringence) is spatially modulated in accordance with the polarisation modulation of the recording light field, i.e., a polarisation holographic grating is recorded. The various possibilities for recording polarisation holographic gratings are known. It has also been shown that the diffraction efficiency (η) depends on the type of polarisation interference pattern, which forms the basis of the polarisation multiplexing. This is based on the fact that at sufficiently large values of photoinduced anisotropy it is feasible to record polarisation gratings with high efficiency, up to 25% for amplitude modulation and up to 100% for phase modulation. When the recording is accomplished with two orthogonal circularly polarised waves, η is strongly dependent on the ellipticity of the reconstructing wave. By varying the ellipticity, η can vary from 0 to its maximum value. If the object and reference waves have parallel polarisations an ordinary intensity interference pattern results, i.e., the light field intensity is sinusoidally modulated. When the two waves have mutually orthogonal polarisations, the intensity of the resultant light field is constant and only its polarisation is periodically spatially modulated in accordance with the change of the

phase shift between them producing a polarisation interference pattern. Both interference effects may be recorded with suitable materials. In the embodiments of the apparatus shown in Figs. 2 and 3, it is contemplated to utilise both effects. In the preferred version the object SLM 26 provides intensity modulation, but the reference beam 16 and the object beam 15 are also orthogonally polarised, to improve the readout SNR.

During the holographic recording in a photoanisotropic material the polarisation interference pattern is recorded as a spatially modulated optical anisotropy.
In the preferred realisation of the method of the invention, a so-called Side Chain Polyester (SCP) is used. In the recording process the molecules of the recording medium, e. g. a SCP compound, are aligned according to the polarisation of the incident light beam. The writing process utilises blue light, and the readout of the hologram is effected with red light. The recording process in e. g. azobenzene SCP material is described in detail in the publication "Side-chain Liquid Crystalline Polyesters for Optical Information Storage", in: Polymers for Advanced Technologies, Vol. 7, pp. 768-776., which is herewith included by reference. Similar materials suitable for holographic recording are also known, and may be used advantageously. The principles of polarisation holography are described in the publication "Polarisation holography. 1: A new high-efficiency organic material with reversible photoinduced birefringence", Appl. Opt., Vol. 23, No. 23, 1 December 1984, pp. 4309-4312, and the publication „Polarisation holography. 2. Polarisation holographic gratings in photoanisotropic materials with and without intrinsic birefringence", Appl. Opt., Vol. 23, No. 24, 15 December 1984, pp. 4588-4591. These latter are also included by reference. An important feature of the polarisation holography is that if the reference beam 16 and the reflected object beam 15 are chosen to be orthogonally polarised, then they may be completely separated by a polarising element. This results in outstanding signal-to-noise ratio (SNR). As shown in Fig. 2, the originally elliptic polarised beam of the write laser 20 and the read laser 21 are transformed into a parallelly polarised object beam 15 and a transversally polarised reference beam 16

(the plane of reference is the plane of Fig. 2.) by the wave-plates 30 and 35, and the polarising beam splitter 23. Upon readout, the parallelly polarised reflected object beam 17 is completely separated from the reflected reference beam 18, which latter is transversely polarised.

It must be noted that the diffraction efficiency also increases, if the polarisation technique is used together with the reflected transmission recording method. This is due to the fact that the polarised reference beam will phase shift with π on the interface layer of a reflective layer 32. That would mean that with a circularly polarised beam the direction of rotation will change to the opposite, but at the same time the propagating direction of the beam also reverses. The result will be that the beam will diffract in the same directions when travelling back through the recording layer.

Returning to Fig. 2, the read objective lens 28 is designed to correct the distortion of the readout. This distortion results from the wavelength difference between the laser 20 and the laser 21. Because of the on-axis configuration of the optical system, the distortions will be axially symmetric, and therefor they may be corrected by an appropriately designed aspheric lens, acting as the objective lens 28. This distortion is less significant for central rays and more significant for the rays close to the edge of the image space.

Fig. 4a-b are a schematic cross-sections of the optical recording medium. Here the recording medium is an optical card 2 used in the optical storage system 1 of the invention. The optical card 2 has a relatively thick - 0,5-1 mm - plastic base plate 31, made of a suitable plastic material, e. g. polycarbonate or PVC. A wavelength selective reflective layer 32 with an approximate thickness of 100 nm is coated on the base plate 31 with vacuum evaporation, sputtering or other suitable process. The purpose of the reflective layer 32 is to reflect during readout the object beam transversing the recording layer 33. Therefore, the reflective layer 32 must be reflecting the readout wavelength, but should advantageously be non-reflecting on the write wavelength. It is desirable to suppress reflection of the writing beams, so that no disturbing interference

results from the reflection of the reference beam 16 and the object beam 15 during writing.

Fig. 5. is a top view of the optical card 2, seen from the recording side, i. e. from the side of the protective layer 34. Though there is nothing in the way for providing a storage surface on both sides of the optical card, in practice only one side is used for data recording, while the other side is provided with written information legible with the naked eye, i. e. a short informative text about the type of the optical card.

The recording on the optical card 2 is made in the form of very small holograms 61, each with a square form and the size of approx. 0.8 x 0. 8 mm^2. In Fig. 5 several other holograms 61i, 61j, 61k are shown, which all have the same structure as hologram 61. The holograms 61 are spaced approx. 200 microns apart from each other, and between them there is provided positioning markers 62 and 63, and eventually identifying markers 64. One set of markers 62 is used for positioning in the X direction, while the other set of markers 63 are used to align the read/write optics in the Y direction. The identifying markers 64 may contain information about the position of the hologram 62 on the optical card 2, and may also contain information about the type of the hologram 62.

Fig. 3. shows a modified version of the write/read optics of the invention presented on Fig. 2. This optical system combines the write optics part 51 and the read optics part 52 into a common unit. The basic configuration contains all the elements of the write optics 51, and the optical path of the write object beam and the write reference beam is principally the same. Accordingly, the combined read/write optics of Fig. 3 comprises the write laser 20, operating in the visible blue region, around 440 nm. The read laser operates in the visible red region, approximately at 630 nm, and is preferably another semiconductor laser or LED, or a He-Ne laser. The beam of the write laser 20 is directed through the half-wave-plate 24, the beam shaping optics 22 and the beamsplitter 23. The light of the read laser 21 is inserted into the optical system through the wavelength selective beam splitter 41. The beam-shaping optics 22 and 22'

transform the Gaussian intensity distribution of the laser 20 and 21 into a square distribution. During writing, the beamsplitter 23 separates the beam into the object beam 15 and the reference beam 16. The reference beam 16 is sent through the quarter-wave-plate 44, towards the reference SLM 26. The reference beam 16 is reflected from the reference SLM 26 back through the quarter wave-plate 44, the beamsplitter 23, another quarter wave-plate 45 and falls on the surface of the optical card 2 through the objective lens system 47, which will be described below. It is necessary to compensate the delay caused by insertion of the second wavelength selective beamsplitter 42 in the optical path of the object beam 15. Therefore, an additional element must be added in the combined read/write optics 3. This is the compensator block 43, which provides the necessary delay in the optical path of the reference beam 16. It must be noted that the wave-plates 44 and 45 of the embodiment of Fig. 3 are electronically controlled, so that they can be adjusted to the wavelength of the write or read beam.

After the beamsplitter 23 the object beam 15 falls on the object SLM 25 through the quarter-wave-plate 36 and the second wavelength selective beam splitter 42. This latter has been added to deflect the reflected object beam 17 of the readout beam towards the detector 29. From the object SLM 25 the object beam 15 is reflected back towards the optical card 2, through the quarter-wave-plate 36, the second wavelength selective beam splitter 42, the beamsplitter 23, and the quarter wave-plate 45. The object beam 15 falls on the surface of the optical card 2 through the same objective lens 47, so that the reference beam 16 and the object beam 15 have a common optical axis to and from the optical card 2. Hence, the combined read/write optics 3 is also built up with an on-axis configuration. The object beam is 15 and the reference beam 16 are modulated by their respective spatial light modulators 26 and 25, similarly to the case with the separate read and write optics parts 52 and 51. The object beam 15 and the reference beam 16 are imaged on the optical card 2 by an objective lens system 47. Other optical components, like lenses, diaphragms, mirrors, etc. may also be used, in order to get a suitable beam shape at the SLM 26 and 25 and on the surface of the optical card 2. The

functioning of the objective lens system 47 is described in detail with reference to Fig. 6a-b.

Detection of the holograms on the optical card 2 is done with the CCD detector 29. The reflected object beam 17 is reflected towards the CCD detector by the wavelength sensitive beam splitter 42. During readout the electronically controllable wave plates 44 and 45 are tuned to the wavelength of the read laser 21.

Referring to Fig. 6a-b, the principle of the wavelength distortion correction means according to a preferred embodiment is shown. In the embodiment of Fig. 3, the wavelength distortion correction means are embodied by the objective lens system 47. The function of the objective lens system 47 is shown with reference to Fig. 6a, with the help of a simplified scheme of the optical setup representing the optical system of Fig. 3. The objective lens system 47 of Fig. 3 consists of one or more aspherical plastic lenses, or aspherical glass lenses. At least one aspheric lens 48 comprises a central region 49 and an annular region 50 in its useful aperture. The aperture with the central region 49 and the annular region 50 is shown in Fig. 6b. As shown in Fig. 6a, during recording, the useful cross-section of the object beam 15 and the reference beam 16 passes through the central region 49 only. During readout, the read reference beam 18 will be confined to the central region 49, but the reflected transmission beam, i. e. the reflected object beam 17 will diffract in greater angle, because its wavelength is longer. Therefore, a fraction of the reflected object beam 17 will pass through the central region 49 and the remaining fraction will pass through the annular region 50. Accordingly, the annular region 50 is shaped so as to compensate the wavelength distortion of the reflected object beam 17, and to provide a distortion-free image of the hologram 61 on the CCD detector 29. The shape of the central region 49 is formed so as to provide an acceptable imaging for the reference beams 16 and 18 and the object beams 15 and 17, both on the reading and the writing wavelengths. Of course, this will be a compromise between the optimal lens shapes for ideal imaging, so both beams

will remain distorted to a small extent. But this distortion is tolerable, because in the central region 49 the angles of incidence are smaller than in the annular region 50.

It must be noted that the reference SLM 26 may be substituted with a mirror as well, both in the combined optics 3 of Fig. 3 and in the separate read and write optics parts 52 and 51 of Fig. 2. The purpose of the reference SLMs 26 is to allow the possibility of the so-called multiplexing using deterministic phase encoding. This method is described in the publication "Volume hologram multiplexing using a deterministic phase encoding method", Opt. Comm. 85 (1991), pp. 171-176. In this multiplexing method a liquid crystal spatial light modulator (LCSLM), in our case the reference SLM 26 is placed in the way of the reference beam. Each pixel of the reference SLM 26 may be switched into two positions: either it adds π to the phase of the incoming beam, or it leaves the phase unchanged. In this way different reference wavefronts can be produced. The set of adjustable phases for a given reference beam represents the address of the corresponding object, and a phase address can be made orthogonal with all other phase addresses. It may be shown that during the reconstruction process a given reference beam will only reconstruct its own corresponding object beam, and theoretically there will be no crosstalk between different objects, but only the detected signal intensity will be lower. The number of independently recordable subholograms within one physical hologram is equal to the number of orthogonal phase addresses. Of course, because of the decrease in the signal intensity, the SNR of the recorded subholograms will decrease as well, so there is a practical limit to the multiplexing. In the most simple embodiment, the reference SLM 26 consists of only two pixels (left-L and right-R). With this system only two orthogonal phase addresses can be given, so two independent subholograms can be recorded on the same area of the material. During the first recording the phase shift introduced by L and R on the reference beam is zero. During the second recording R shifts the incoming phase by π, but the phase shift at L is still zero. These two phase addresses (1,1) and (1,-1) are orthogonal. Accordingly, the area of the hologram can be divided into two parts: a left (HL) and a right (HR) part, which we will call "partial holograms". It may be shown that the

contents of these partial holograms can be detected independently from each other, if the reference SLM is switched into the two orthogonal phase address states. The simplest symmetric arrangement approximating the circular image of the optics uses an SLM 26 divided into four (two by two) segments.

It has turned out that this multiplexing technique works well for thin holograms. The number of multiplexed holograms can be increased by increasing the pixel number of the LCSLM. In order to avoid crosstalk, there must be no overlap between the partial holograms. The main factor that restricts the maximum number of multiplexed subholograms is the diffraction limited spot size of an LCSLM pixel. The number of the practically achievable multiplexed subholograms is approximately 10 to 100.

Beside the above described phase encoding, the so-called polarisation multiplexing technique may be used as well.

It is known that for the case of recording with two orthogonal circularly polarised waves, the diffraction efficiency is strongly dependent on the polarisation of the reconstructing wave, particularly on its ellipticity. It is possible to control the readout wave ellipticity with a $\lambda/4$ plate. The maximum value of the diffraction efficiency η in the +1 order is reached when the polarisation of the reconstructing wave coincides with that of the reference wave during the recording and falls to zero at orthogonal polarisation. At the same time the change of η in the -1 order is described by a similar relation, shifted at 90°; when η is at its maximum in the +1 order, in the -1 order it is equal to zero and vice versa. Therefor, the polarisation multiplexing method is the following:

- Take the first exposure with left-hand circular polarisation reference beam ('A' hologram)
- Take the second exposure with right-hand circular polarisation reference beam ('B' hologram)
- If we use left-hand circular polarisation read-out beam then the diffraction efficiency of the 'A' hologram will be maximum and the diffraction efficiency of the 'B' hologram will be minimum and

we will reconstruct the 'A' hologram while
the overlapping of the 'B' hologram will be minimum.

- If we use right-hand circular polarisation read-out beam then we will reconstruct the 'B' hologram while the overlapping of the 'A' hologram will be minimum.

Accordingly, the sensitivity of η to the polarisation of the recording beam makes it possible to double the information capacity of the recording. It is straightforward that in the optical recording method of the invention, the polarisation multiplexing could be combined with deterministic phase encoding multiplexing. The appropriate phase encoding of the SLM 26 is controlled by the data processor 6.
In a practical system using the information storage method of the invention a ten- to hundredfold phase multiplexing is contemplated. Polarisation multiplexing necessitates additional optical or mechanical elements to rotate the polarisation planes of the object and reference beams, and the polarising elements.
Such a system is also feasible, though the involved number of the mechanical and optical elements would make the system more complicated than the demonstrated preferred embodiments. In theory wavelength multiplexing is also possible, but the SCP materials inherent sensitivity to the write and read wavelengths makes this solution impractical.

Finally, Fig. 7 is a schematic diagram of a possible mechanical construction of the optical system 1 of the invention. The optical system 1 has two main mechanical components, the read/write optics 3 and the card positioning mechanism 4. The read/write optics 3 comprises the holographic read/record optics and the fine servo. The card positioning mechanism comprises the X-directional translating chassis 55, moved by the X-motor 58, preferably a stepper motor. The chassis 55 is gliding on rails relative to the base 56. Within the chassis 55 there is arranged an Y directional translating chassis 59, actuated by the Y-motor 57. It is understood that other solutions

are equally well suited to provide for the positioning of the optical card 2 relative to the read/write optics 3. For example, translation mechanisms may be provided to move the read/write optics 3, while the optical card 2 remains fixed, and the card positioning mechanism only performs the stable fixing of the optical card 2, which is inserted into the card reader device by an external user, and after the reading and/or writing the card positioning mechanism ejects the optical card.

The optical information storage system based on the principles outlined in the invention has very favourable parameters compared with the available optical cards. With a 256 x 256 bitmap image pixel resolution and a 1024 x 1024 real image pixel resolution imaged onto approx. 0.8 mm x 0.8 mm holograms, with four-fold multiplexing, the data capacity of a credit-card sized optical card may well reach 100 Mbytes. Assuming the readout of four holograms in a second, which is not unrealistic, a data transfer rate of 100 kByte/s can be achieved.

It must be noted that the wavelength distortion correction means may be realised by other elements in the system. Especially, it is also foreseen to utilise a high resolution CCD detector 29, and to perform the distortion correction by a suitable software, which would analyse the image on the CCD detector 29. This task could be done by the data processor 6, but the use of a specially dedicated processor unit is also contemplated.

The data processor 6, or an other encoding unit may be used advantageously for the encoding of the recorded information on the holographic optical card 2. Holographic recording is inherently more secure compared to traditional magnetic or other types of optical cards. According to the invention, we propose to use the advantageous properties of the holographic recording for the implementation of a coding method, which will be explained with reference to Fig. 5.
As we have shown above, in a preferred mode of the recording method of the invention, the information is in the form of several discrete holograms or

subholograms recorded in different physical and/or logical recording locations on the optical card. These different locations are symbolised by the holograms 61i, 61j, and 61k. The holograms contain data sets, where the sequence of the data sets together constitute the recorded information. E. g. to reproduce the information content of a specific file, the holograms should be read in the following order: 61j, 61k, 61i. This order or sequence of the location of the holograms is determined randomly, i. e. the data sets contained in the holograms are recorded in a random sequence of the recording locations. It must be noted that the term „random" may also mean pseudo-random ordering, or the ordering by a secret, pre-determined, and not obvious sequence.

Though in Fig. 5 a random sequence of the physical recording locations is shown, it must be stressed that the random locations may also mean random logical locations.

In order to maintain high write and readout data rate, it is especially contemplated that the physical locations should be in a natural order during recording or reading, so that the quick mechanical re-positioning of either the card 2 or the read/write optics 3 from one recording location to another will not pose problems. In this latter case the randomization of the locations is made only in the logical locations, and the physical locations are ordered. If the information is recorded in multiplexed holograms, each multiplexing mode represents a multiplexing address. In this case the logical recording locations may be identified by the multiplexing address.

In a proposed embodiment of the optical card 2 and the read/write opics 3, the information is recorded by polarisation holography using phase-code multiplexing.

Thereby one hologram contains several, maybe as much as one hundred phase-coded multiplexed subholograms, each subhologram containing one data set. In this case the logical recording locations of the data sets within one hologram 61 are identified by the phase code address n, where n may be a number from 1 to 100. The identifier of the location of the n-th data set in the hologram 61i may be denoted as 61i/n.

The data are recorded and read in the following manner:

The first data set is recorded to the location with the identifier 61j/n. The identifier of this location is stored to the directory of the card 2, and encrypted, so that only

authorised persons are allowed to read the identifier. Thereafter, the next data sets are recorded in the locations 61j+1/p, 61j+2/q, 61j+3/r, 61j+4/s, etc. The physical locations 61j, 61j+1, 61j+2, 61j+3, 61j+4 represent holograms following each other in the same row or column on the optical card 2. The series n,p,q,r,s etc. represent a random sequence. It is also feasible if the physical hologram 61j remains the same, and only the logical locations 61j/n, 61j/p, 61j/q, 61j/r, 61j/s, etc. are recorded in a random sequence, until all subholograms 61j/1-61j/100 are recorded. The recording than continues in the next physical hologram 61j+1, or, alternatively, in the randomly selected physical hologram 61k.

The identifier of the location of the following data sets is stored in the previous data sets. In the example above, the identifier 61j+1/p is stored in the data set of the subhologram 61j/n, the identifier 61j+2/q is stored in the data set of the subhologram 61j+1/p, and so on.

It is also possible to store the random sequence of the locations of the data sets together, in a directory area of the optical card 2. In this case the whole sequence is encrypted and/or made inaccessible for unauthorised users. The access to the random sequence is allowed with e. g. a PIN code.

While the invention has been shown with reference to the specific embodiments of the attached drawings, other advantageous embodiments may be realised by those skilled in the art. Obviously, the hologram recording medium could be made in the form of an optical disk or tape, and the optical recording apparatus may be modified accordingly, with appropriate disk or tape positioning and rotating/winding mechanisms, instead of that used for the positioning of the optical card 2.

Claims

1. Method for the recording and reading of data on a recording medium, using a holographic recording medium with a thin holographic recording layer,, preferably an optical card, and holographic write/read apparatus for the recording medium, wherein the recording of the information is in the form of data pages stored as thin Fourier holograms, characterised by
using reflected transmission and polarisation holography with different write and read wavelength, and
during reading correcting the distortion in the readout channel caused by the difference between the write and read wavelengths.

2. Method according to claim 1, wherein the wavelength distortion is corrected by optical and/or software means.

3. Method according to claim 1, wherein the holograms are recorded as on-axis holograms.

4. Method according to claim 1, wherein the recording and reading is made with polarisation multiplexing and/or phase-code multiplexing.

5. Holographic recording medium, preferably an optical card, having a carrier substrate, a holographic recording layer sensitive to light, and a reflection layer between the carrier substrate and the recording layer, characterised by that the recording layer is a polarisation sensitive polymer material, and the thickness of the recording layer is 0.5-2 times the wavelength of the reading and/or recording light.

6. Holographic recording medium, preferably an optical card, according to claim 5, wherein the reflection layer is a wavelength selective mirror reflecting on the read wavelength and transmitting or absorbing on the write wavelength.

7. Holographic recording medium, preferably an optical card according to claim 5, wherein the recording layer is an azobenzene SCP layer.

8. Holographic recording medium, preferably an optical card according to claim 5, wherein the recording layer is covered by a protective layer.

9. Apparatus for the writing and reading of a holographic recording medium, preferably an optical card, having a recording medium holding and/or positioning mechanism, movable or fixed read and write optics,
the write optics comprising a polarised writing light source, a polarising beam selector for separating the reference beam and the object beam, an object beam modulating unit, a polarisation wave plate, an objective lens for imaging the object beam onto a recording layer, and further the read optics comprising a polarised reading light source, and a polarisation selective beam splitter for separating the reference beam and the image beam, a light detector and an objective lens for imaging the image beam onto a light detector,
characterised by that the wavelength of the reading light source is different from the writing light source, and
the read optics comprise wavelength distortion correcting means for correcting the distortion of the reconstructed image caused by the difference in the wavelength of the reading and writing light.

10. Apparatus according to claim 9, wherein the wavelength of the writing light source is between 400-500 nm, and the wavelength of the reading light source is between 600-700 nm.

11. Apparatus according to claim 9, wherein the wavelength distortion correcting means of the read optics comprise an aspherical plastic objective lens.

12. Apparatus according to claim 9, wherein the object beam and the reference beam in the read optics and/or the write optics have a common optical axis, and there is provided a polarisation selective beam splitter for separating the reflected reference beam from the reflected object beam.

13. Apparatus according to claim 9, wherein polarisation encoder means are provided in the optical path of the reference beam.

14. Apparatus according to claim 9, wherein the polarisation encoder means are comprising a LCSLM.

15. Apparatus according to claim 9, wherein the read optics and the write optics have a common objective lens for imaging the reference and object beams onto a recording layer and for imaging the reflected object beams onto the read detector.

16. Apparatus according to claim 9, wherein the common objective lens is an aspheric lens for the correction of the wavelength distortion, the aspheric lens having a central region and an annular region in its aperture, where the central region of the aspheric lens is tuned to the wavelength of the writing light source for focussing the write object beam onto the recording layer, and at the same time tuned to the wavelength of the read light source for imaging the read object beam onto the detector, and further the annular region of the lens is tuned to the wavelength of the read light source for imaging the reflected beam onto the detector.

17. ~~Holographic data storage system with a holographic recording medium, preferably~~ an optical card and a read/write apparatus for the holographic recording medium, particularly with the recording medium according to claim 5 and a read/write apparatus according to claim 9,
characterised in utilising reflected transmission and polarisation holograms with different read and write wavelength, together with distortion correction means for

correcting the distortion caused by the difference between the read and write wavelength.

18. The system according to claim 17, wherein the data storage capacity is multiplied by polarisation and/or phase code multiplexing.

19. Method for coding of the recorded information on a holographic optical recording medium, preferably an optical card, where the information is recorded in the form several discrete holograms and/or subholograms recorded in different physical and/or logical recording locations on the optical recording medium, the holograms containing data sets, where the sequence of the data sets together constitute the recorded information,
characterised by that the data sets are recorded in a random sequence of the recording locations.

20. The method according to claim 19, wherein the information is recorded in multiplexed holograms, and the logical recording locations are identified by the multiplexing address.

21. The method according to claim 19, wherein the information is recorded by polarisation holography using phase-code multiplexing, where one hologram contains several phase-coded multiplexed holograms, and the logical recording locations are identified by the phase code address.

22. The method according to claims 19, wherein the location of the first data set is stored, and the location of the following data sets are stored in the previous data sets.

23. The method according to claims 19, wherein the random sequence of the data sets are stored and encrypted and/or made inaccessible for unauthorised users.

A meghatalmazott

Dr. Bokor Tamás
szabadalmi ügyvivő
az S.B.G. & K. Nemzetközi
Szabadalmi Iroda tagja
H-1062 Budapest, Andrássy út 113
Telefon: 34-24-950, Fax: 34-24-32

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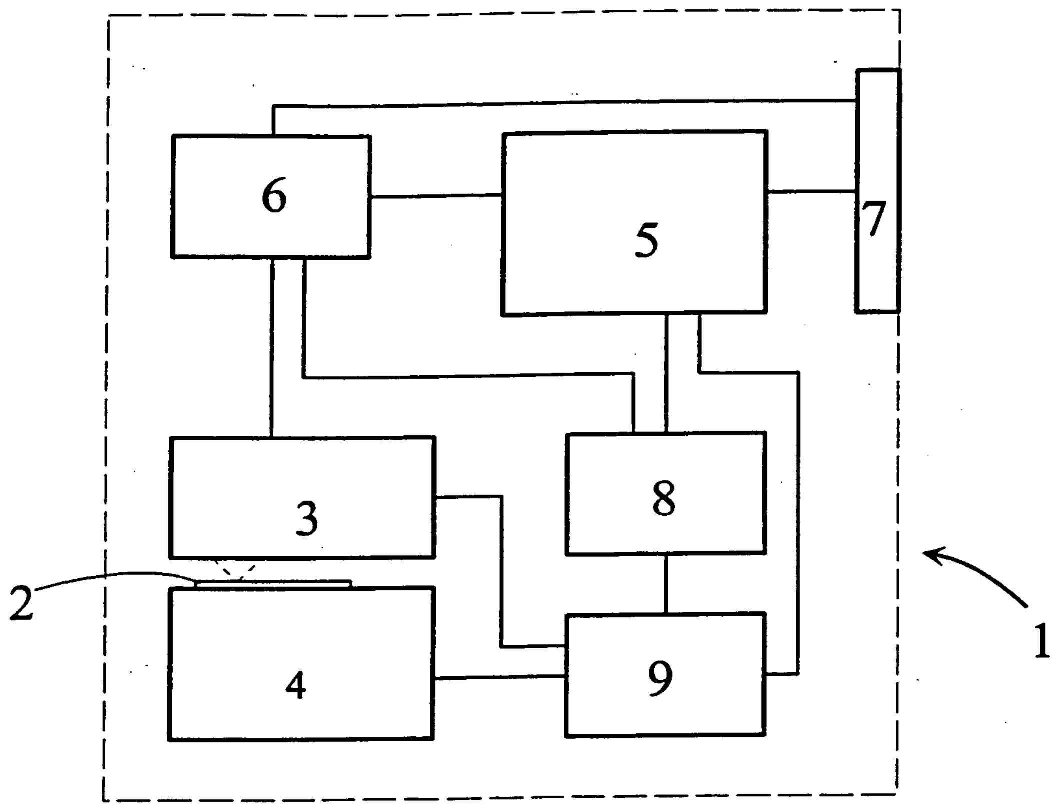

Fig. 1

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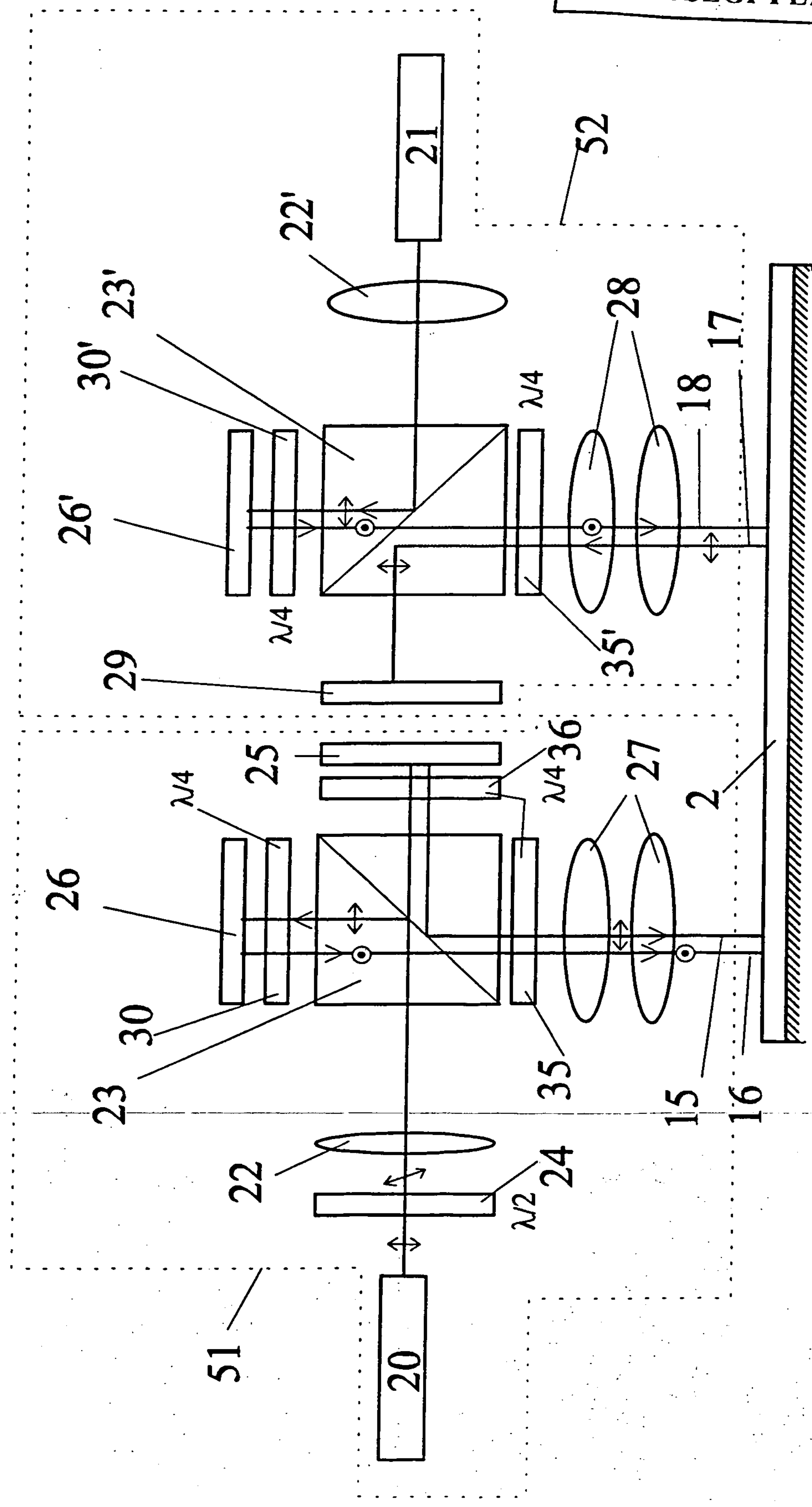
Fig. 2



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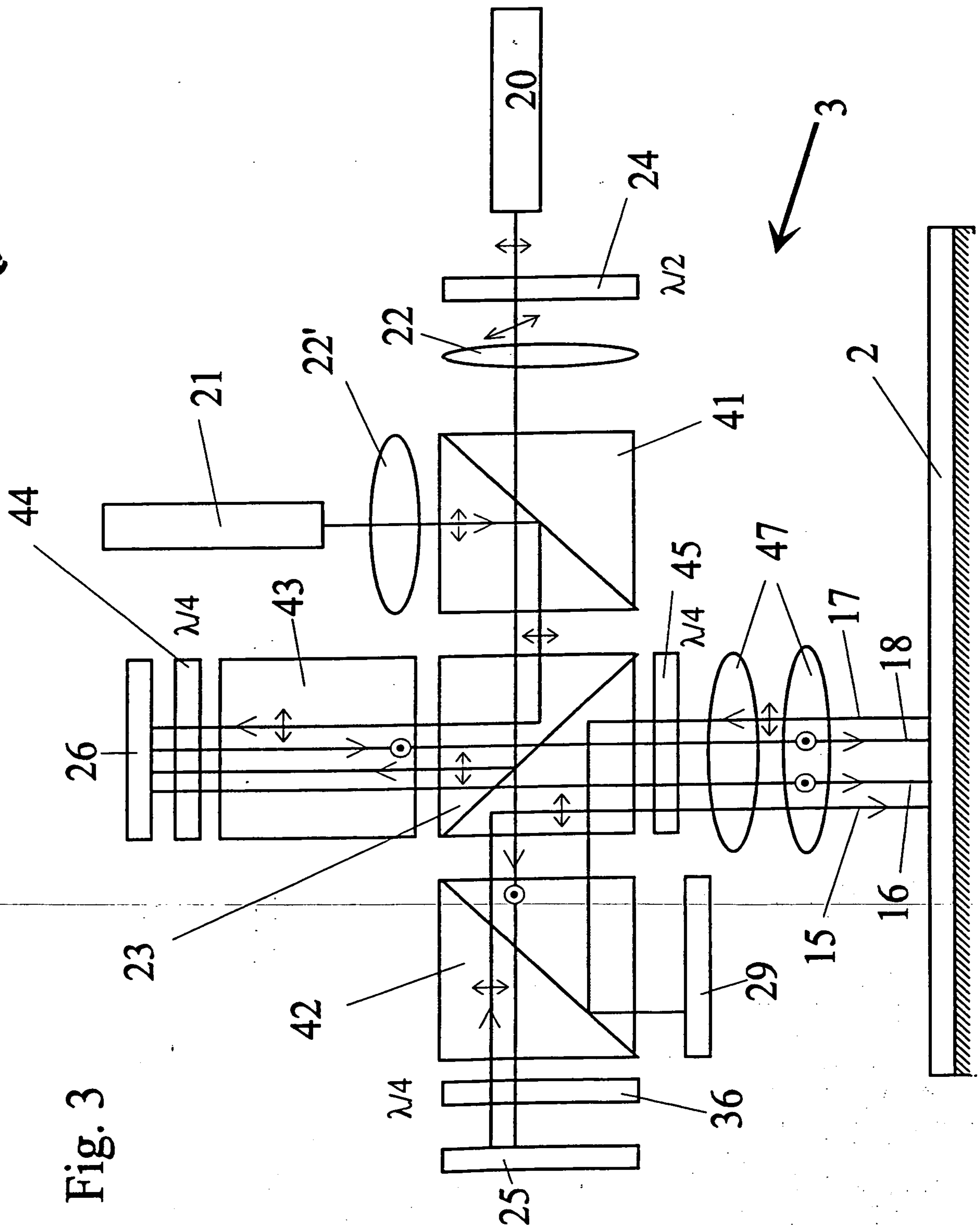

Fig. 3

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Fig. 4a

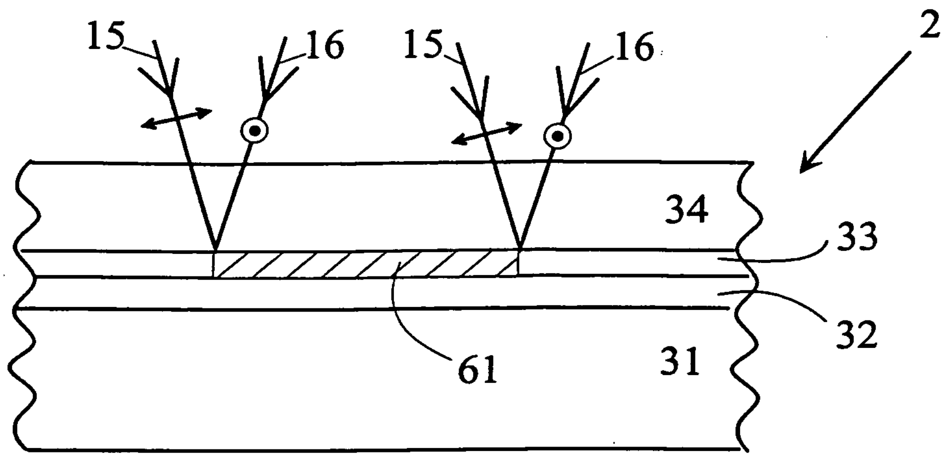


Fig. 4b

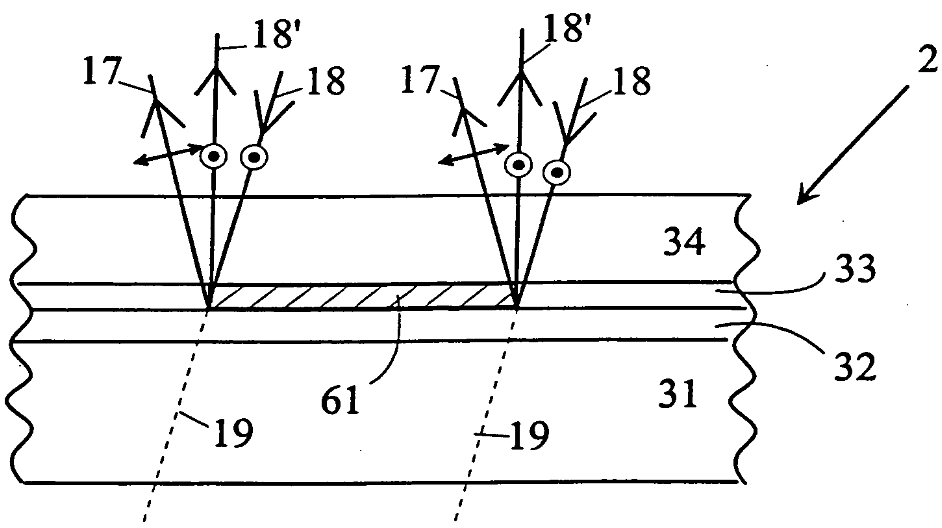
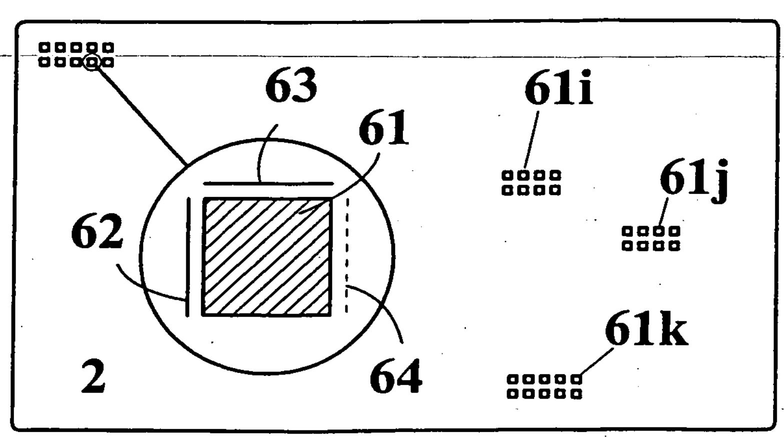


Fig. 5



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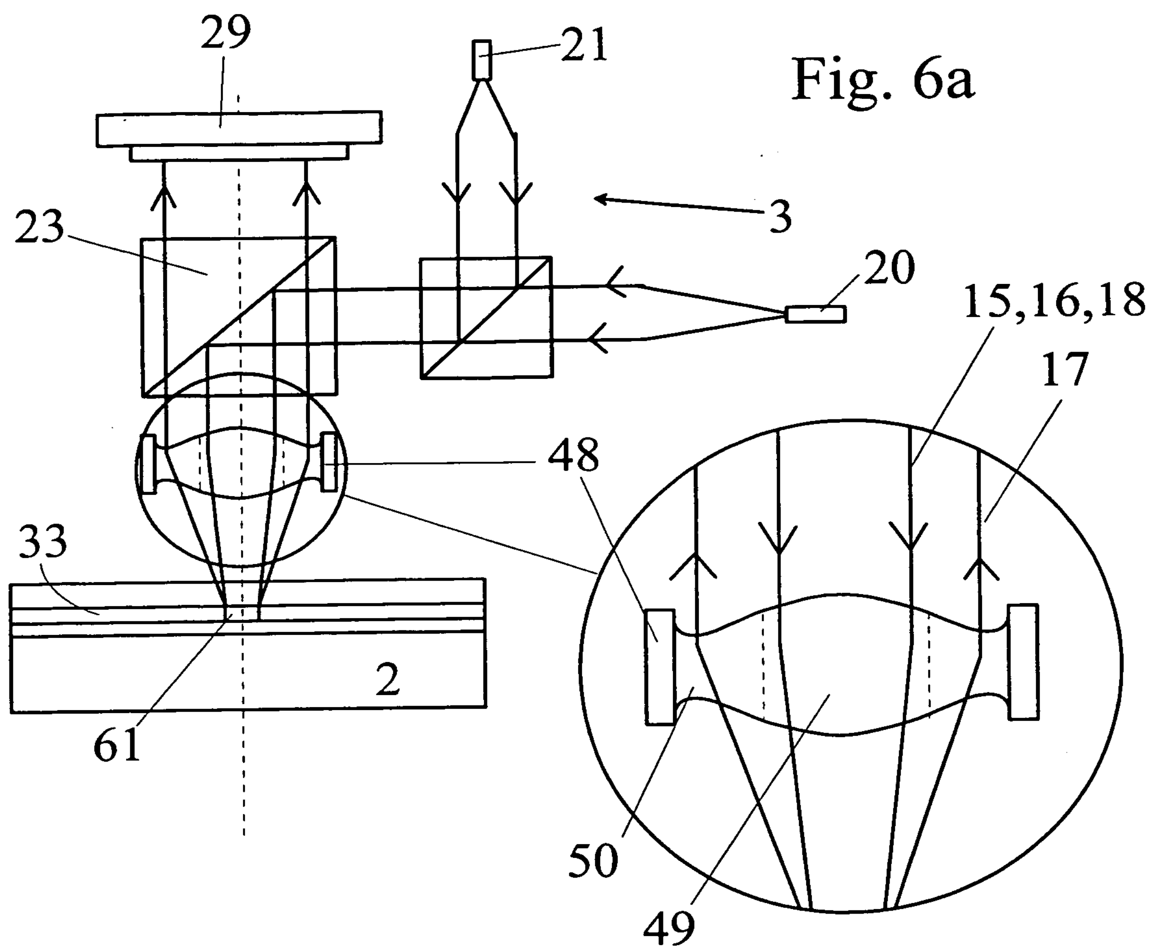

Fig. 6a

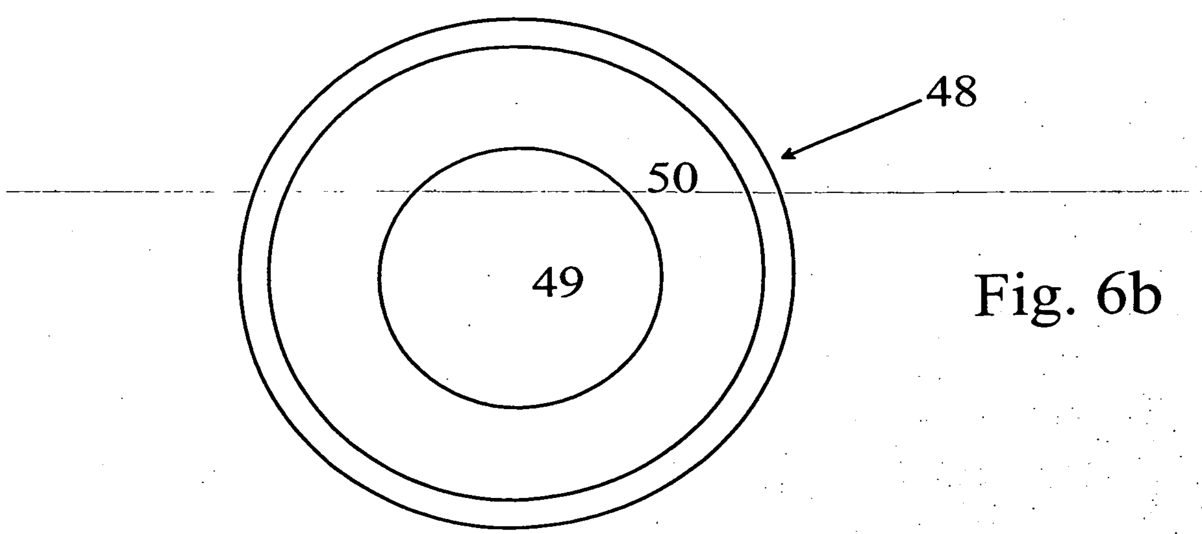

Fig. 6b

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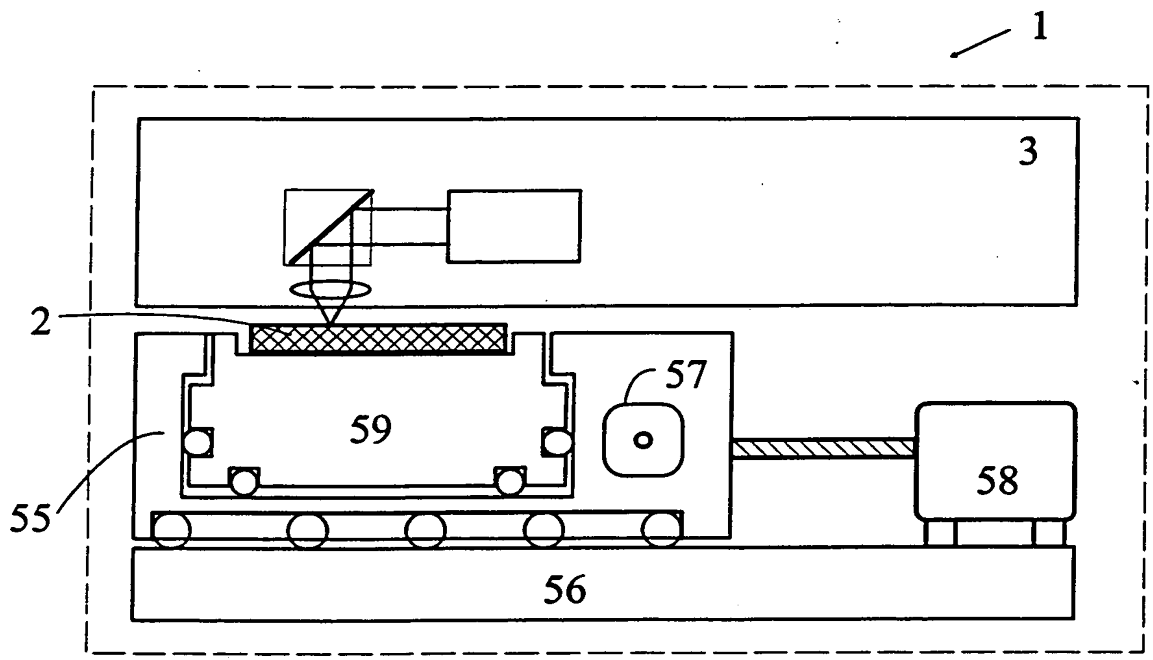
Fig. 7



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